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**Conference Paper**

## Ex ante and ex post analysis of great infrastructure investment projects - the case of the fixed Oresund link

39th Congress of the European Regional Science Association: "Regional Cohesion and Competitiveness in 21st Century Europe", August 23 - 27, 1999, Dublin, Ireland

**Provided in Cooperation with:**

European Regional Science Association (ERSA)

*Suggested Citation:* Madsen, Bjarne; Jensen-Butler, Christopher (1999) : Ex ante and ex post analysis of great infrastructure investment projects - the case of the fixed Oresund link, 39th Congress of the European Regional Science Association: "Regional Cohesion and Competitiveness in 21st Century Europe", August 23 - 27, 1999, Dublin, Ireland, European Regional Science Association (ERSA), Louvain-la-Neuve

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**EX ANTE AND EX POST ANALYSIS OF GREAT INFRASTRUCTURE INVESTMENT  
PROJECTS  
– THE CASE OF THE FIXED ØRESUND LINK**

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Paper presented at the  
European Regional Science Association Conference  
in Dublin,  
August 23-27, 1999

# EX ANTE AND EX POST ANALYSES OF GREAT INFRASTRUCTURE INVESTMENT PROJECTS – THE CASE OF THE FIXED ØRESUND LINK

## 1. Introduction

In Denmark in recent years there has been a substantial debate both popular and academic concerning the consequences of fixed links both for traffic flows and for regional economies. Denmark is a prime location for this type of discussion as three major fixed links are the subject of debate: the Great Belt Link, recently opened, the Øresund link between Denmark and Sweden, to open in 2000 and the Femern link between Denmark and Germany, still on the drawing-board. The debate has until now, naturally enough, been centred on *ex ante* analyses, though soon *ex post* studies will be possible. The aim of the present paper threefold. First, an integrated model designed to analyse the interrelated effects of changes in the transport system and regional economic change is presented. Second, given the model, examination is made of the basic differences between *ex ante* and *ex post* analyses. Third, a decomposition of the regional economic and traffic flow effects into the effects of infrastructure projects in isolation, the effects of infrastructure changes and the effects of regional economic change is presented. One more focussed aim of the study is to examine the specific effects of the Øresund link. This link, which is at present under construction, is a fixed link between Denmark (Copenhagen) and Sweden (Malmö) and is 22 km long. The location of this link together with the other two fixed links is shown in figure 1 and basic data concerning the links are provided in table 1.

## 2. Danish studies of changes in the transport system and regional economic development.

First, a number of *ex ante* studies are outlined, followed by description of an approach to *ex post* analysis.

### 2.1 Earlier *ex ante* studies

A number of studies of the effects of the fixed Øresund link have been undertaken. One main group has been concerned with changes in traffic flows and their environmental consequences. The Øresund Consortium, which has overall responsibility for construction of the link, has constructed a data base and a traditional 4 step traffic model suggesting that daily traffic will increase from 5,200 cars in 1996 to 10,200 in 2000 rising to 16,700 in 2030. For lorries a corresponding proportional increase is forecast, starting from 939 in 1996. (Øresundskonsortiet 1998). The Øresunds Consortium has also developed a Greater Copenhagen Transport Model (Carl Bro Gruppen 1995).

Another main group deals with the more general regional economic problem. The Greater Copenhagen Statistical Office has developed a land use model for the region involving forecasts which incorporate local planning decisions concerning housing and industrial building and a population forecast. These forecasts are used as an input in the Greater Copenhagen Traffic model. AKF has used the AIDA model to forecast changes in key economic variables in Danish regions and has been used to model change in the Copenhagen municipal economy (Holm et al, 1995). LINE, a new local economic model developed by AKF has been used in a comparative study of economic development in Greater Copenhagen and the rest of Denmark (Ekspertudvalget, 1998).

A third group deals with analyses of regional Cupertino and potential barriers to interaction in the Øresund region. The Scandinavian Academy of Management (SAMS) has produced a number of reports on strategic questions both at a general and a sectoral level, using management science approaches (Berg et al 1995). These analyses can be used as a point of departure for analysis of changes in traffic flows and regional development. Matthiessen & Andersson (1993) have undertaken an analysis of regional economic growth potential in the Øresund region after the opening of the fixed link, using an institutional approach. AKF has undertaken a study of transport and border barriers in relation to interregional trade in the Øresund region (Madsen & Jensen-Butler 1997) and a study of commuting (Bacher et al, 1995). Both studies indicate that there are significant border barriers to cross-Øresund interaction. The Institute for Border Region Research has undertaken studies of cross-border interaction across the Danish-German land border which show that border trade is a function of short-distance price differences and that cross-border commuting is very limited. (Bygvrå 1997, Smith 1986). The Danish Transport Council has published a study of border trade with petrol and diesel (Transportrådet 1998) showing the influence of price differences on this trade.

Other Danish studies related to these three groups include a major study of the regional economic effects of the fixed Great Belt Link (Madsen & Jensen-Butler 1991, Jensen-Butler & Madsen 1996) and of the Femern link (Jensen-Butler & Madsen, 1999).

## 2.2 Ex post analyses: General considerations

As can be seen from the previous section, these studies deal with:

- i) changes in traffic flows
- ii) changes in relations between regions measured in changing levels of interaction in the transport system
- iii) changes in regional economic activity, typically measured by changes in employment and income (GDP)

As can be seen in section 2.1, most analyses are isolated in the sense that changes in traffic flows and changes in regional economic variables are treated independently. An ex post analysis cannot treat each set of factors independently as the changing traffic flows and the changing pattern of regional development are a result of the combination of changes in causal factors and their interaction effects.

Looking at traffic across Øresund, the point of departure would be changes in traffic flows across

$$\Delta T_{ij}^{pmr} = T_{ij,t_1}^{pmr} - T_{ij,t_0}^{pmr} \dots\dots\dots(1)$$

Where:

$\Delta T_{ij}^{pmr}$  : Change in traffic flow between zones i and j, for trip purpose p, mode m and route r

$T_{ij,t_1}^{pmr}$  : Traffic flow for time t<sub>1</sub> (after the opening of the Øresund link)

$T_{ij,t_0}^{pmr}$  : Traffic flow for time  $t_0$  (before the opening of the Øresund link)

The change in other variables can be treated in the same manner, variables such as aggregated transport flows, output or employment.

It is assumed that modelling of the traffic flow variables (the right hand side of equation (1)) can be undertaken using an integrated regional economic and transport model, M. It is assumed that M can, with a degree of model error, replicate the real traffic flows before and after the link is opened, so:

$$T_{ij}^{pmr} = M(E_{TR}^{\emptyset F}, E_{TR}^{OI}, E_{ECON}) + \text{model error} \dots \dots \dots (2)$$

Where:

$E_{TR}^{\emptyset F}$  : exogenous transport variables related to the fixed Øresund link (ØF)

$E_{TR}^{OI}$  : exogenous transport variables related to other transport infrastructure (OI)

$E_{ECON}$  : exogenous economic variables (ECON)

On this basis, changes in traffic flows are given by:

$$\Delta T_{ij}^{pmr} = (M(E_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) + \text{model error for } t_1) - (M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON}^{t_0}) + \text{model error for } t_0) \dots \dots \dots (3)$$

On this basis, the difference between a limited ex ante analysis and a more comprehensive ex post analysis be demonstrated. In an isolated ex ante analysis changes in traffic flows are calculated as follows:

$$\Delta T_{ij}^{pmr} = (M(E_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_0}, E_{ECON}^{t_0}) + \text{model error for } t_0) - (M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON}^{t_0}) + \text{model error for } t_0) = M(E_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_0}, E_{ECON}^{t_0}) - M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON}^{t_0}) \dots \dots \dots (4)$$

In a comparative static ex ante analysis, only the exogenous variable related to the fixed Øresund link is changed. By definition, model error disappears.

In an ex post analysis the change in traffic flow is instead decomposed into three components:

$$\begin{aligned}
\Delta T_{ij}^{pmr} &= (M(E_{TR}^{\emptyset F, t_1}, E_{TR}^{OI, t_1}, E_{ECON}^{t_1}) + \text{model error for } t_1) \\
&\quad - (M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_0}, E_{ECON}^{t_0}) + \text{model error for } t_0) \\
&= (M(E_{TR}^{\emptyset F, t_1}, E_{TR}^{OI, t_1}, E_{ECON}^{t_1}) - M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_0}, E_{ECON}^{t_0})) \\
&\quad + (M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_1}, E_{ECON}^{t_1}) - M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_0}, E_{ECON}^{t_0})) \\
&\quad + (M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_0}, E_{ECON}^{t_1}) - M(E_{TR}^{\emptyset F, t_0}, E_{TR}^{OI, t_0}, E_{ECON}^{t_0})) \\
&\quad + \text{model error for } t_1 - \text{model error for } t_0 \dots \dots \dots (5) \\
&= \text{effect of the fixed Øresund link} \\
&\quad + \text{effect of other transport infrastructure improvements} \\
&\quad + \text{effect of economic changes} \\
&\quad + \text{model error for } t_1 - \text{model error for } t_0
\end{aligned}$$

In an ex post analysis the effect of the fixed Øresund link is calculated alone by using model M under the assumption that the exogenous variables related to the fixed link are set equal to values which correspond to the after situation, whilst all other exogenous variables are assumed to be equal to values corresponding to the before situation. The effect of other transport infrastructure improvements are calculated by adding the after values for this component. Finally the effects of economic changes can be included in the same manner. In this way, the total effect is divided into three partial effects.

Here, the procedures used to undertake ex ante and ex post analyses have been described. The next step is to examine model M. However, before doing so, it should be noted that there are a number of methodological issues which must be addressed in any decomposition analysis.

### 2.3 General questions concerning decomposition

Decomposition techniques have been used extensively in regional economics. Reviews and applications have been provided by Wolff (1985) Dietzenbacher (1997) and Andersen (1998). The best known technique in regional economics is perhaps shift-share analysis, where growth is decomposed into a national component, a structural component and a residual or regional component. A well-developed tradition for decomposition is to be found in input-output modelling (Rose & Casler, 1996). Here the principal and most simple division into components is between changes in total demand, final demand and intermediate consumption. (For a Danish example of decomposition of energy consumption using national input-output models, see Wier 1998 and for regional income growth see Madsen et al. 1998). The general decomposition problem relates to the fact that multiple equation models can be used to decompose growth. A multiple equation model can be used to undertake model calculations to investigate the effects of changes in a number of exogenous variables. A special variant of the multiple equation model approach is the single equation model estimated using econometric techniques. Here the contribution of independent variables to changes in traffic flows and regional economic activity can be determined.

In the most general sense, economic models are used to decompose growth into explanatory components. A number of problems arise from these approaches to decomposition, problems that are discussed below and the methodological choices that have been made in the present study are examined.

### ***Single equation/ multiple equation models***

Other things being equal, a multiple equation model is a model in structural form, whilst a single equation model can be regarded as a many equation model in reduced form. In the present study a multiple equation model (LINE) has been chosen. The Danish regional research tradition in the analysis of regional economic growth has typically employed single equation models, (see for example Groes & Heinesen, 1997 and Kristensen & Henry 1998, who use a two-equation model). A general discussion of the advantages of using models in structural form is provided by Lucas (1976). In the case of Danish regional models, Madsen & Jensen-Butler (1998a) argue for a formulation in structural form rather than reduced form multiplier models.

### ***Causal structure***

The sequence of decomposition should ideally be determined using an underlying causal model. In some cases (for example, shift-share analysis) the decomposition sequence represents an underlying theoretical hierarchy of causality. In other cases, the sequence reflects the structure of the economic model lying behind. For example, the Keynesian demand-driven model will start with demand which generates production, whilst a supply side growth model will start with factors of production which are used to generate income. LINE is a Keynesian demand-driven model, which starts with production, which generates income, which in turn generates demand. The model will in the future be developed as an interregional general equilibrium model, improving the theoretical basis of the decomposition.

### ***Cumulative or single component decomposition***

Decomposition can, in principle, be undertaken in two different ways. Cumulative decomposition involves the successive inclusion of the effects of different components, starting with the first set of factors, then adding the second set to explain the residual arising from application of the first set, followed by application of a third set of factors to explain the residual arising from the application of the second set and so on. In principle, total growth is explained after application of the last set of explanatory factors and the model reproduces the growth pattern at the end of the period. Cumulative decomposition faces the basic problem that the magnitude of the effects of the individual elements is affected by the order in which the factors are applied. This is because the difference between the 1980 and 1995 level of any one factor may influence the calculation of the effects of succeeding factors.

In order to avoid the problem of order, decomposition can be undertaken as a set of isolated calculations, where the exogenous variables are given their 1995 values and the calculations are performed on the 1980 values for each step, starting at the beginning each time. One set of changes therefore does not affect calculation of any other set of changes. The disadvantage of this method is that the sum of the isolated elements of the decomposition will not necessarily (and not usually) be equal the total growth in the variable in question, here disposable income. It is difficult to interpret the positive or negative residual appearing from this type of analysis. In this study both types of decomposition can be applied and a major divergence between the two would be a cause for concern.

### ***Forward or backward***

Decomposition can, in principle, be undertaken forwards or backwards in time. In this study, as in the previous section, both a forward and backward procedure can be used, where the backward procedure starts with economic components, followed by transport components.

### 3. Model

In this section the structure of an integrated regional economic and transport model will be described. First, the links between the regional economic model and the transport model are described. Second, the detailed structure in the regional economic model are described. The discussion in this section is developed in depth, as analyses based on traditional transport models (for example analyses of observed additional generated traffic after the opening of a fixed link) usually ignore the regional economic changes which cause changes in traffic flows.

#### 3.1 General overview of the model

The link between the regional economic and the transport components can be seen in figure 2. The model is simultaneous as there are linkages in both directions. Spatial interaction forms the link from the regional economic model, LINE, to the transport model and transport costs form the link in the opposite direction. Other links are to be found within the overall model. For example, demand for the transport commodity is determined in the transport model, whilst supply is met by interregional trade in the transport commodity.

In the following the main area of interest is the economic model and its linkages to the transport model. In relation to a traditional free-standing transport model the economic model has replaced the trip generation, attraction and distribution steps by an economic model for interaction (trade, commuting etc) and a model for trip frequency.

#### 3.2 The interregional general equilibrium model, LINE

In this section an overview of the LINE model is presented. First, the full model is shown graphically, followed by the more limited model where the transport element of LINE is examined.

##### 3.2.1 LINE: an overview

Figure 3 shows the general model structure<sup>1</sup> employed in LINE. The horizontal dimension is spatial: place of work, place of residence and place of demand. Production activity is related to place of work. Factor rewards and income to institutions are related to place of residence and demand for commodities is assigned to place of demand. The vertical dimension follows with its five-fold division the general structure of a SAM model. Production is related to activities; factor incomes are related to i) activities by sector ii) factors of production by qualification and iii) institutions: households and firms; demand for commodities is related to wants (aggregates of commodities or components).

The real circuit corresponds to a straightforward Keynesian model and moves clockwise in figure 4. Starting in cell AE in the upper left corner, production generates factor incomes in basic prices including the part of income used to pay commuting costs. This factor income is redistributed from activities to factors (cell AE to cell AG), where labour force are into qualification groups, sex and age. Factor income are then transformed from place of production (AG) to place of residence (BG) through a commuting model. In this process transport costs are subtracted from factor income. Disposable income is calculated in a sub model where taxes are deducted and transfer and other incomes are added. Disposable incomes are distributed from factors (BG) to households and firms (BH). This is the basis for determination of private consumption in market prices, including transport, by place of residence (BW). Private consumption is assigned to place of demand (DW)

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<sup>1</sup>In figure 3 the real circuit of LINE is presented. In figure 5 the price-cost circuit of LINE is presented.



using a shopping model. In this process transport costs related to shopping are subtracted. Private consumption, together with intermediate consumption, public consumption and investments constitute the total local demand for commodities (DV) in basic prices through a USE matrix. In this transformation from market prices to basic prices (from DW to DV) commodity taxes and trade margins are subtracted. Local demand is met by imports from other regions and abroad in addition to local production. Through a trade model exports to other regions and production for the region itself is determined (from DV to AV). Adding export abroad, gross output by commodity is determined. Through a MAKE matrix the cycle returns to production by sector (from AV to AE).

The price/cost component is the anticlockwise circuit in figure 5, corresponding to the dual problem. In cell AE sector basic prices (current prices) are determined by costs (intermediate consumption, value added and indirect taxes) though excluding transport costs. Through a reverse MAKE matrix, sector prices by sector are transformed into sector prices by commodity (from AE to AV). In the trade model lying between AV and DV, transport costs related to trade are added transforming the value of commodities into basic prices including transport costs. These are then transformed into market prices through inclusion of retailing and wholesaling costs and indirect taxes (from DV to DW). This transformation takes place using a reverse USE matrix. Finally, private consumption is transformed from place of demand to place of residence in market prices including transport costs (from DW to BW).

The following is a brief and simplified exposition of the model which is described more fully below. Throughout the first half of the preliminary exposition (3.2.2-3) fixed prices are employed, whilst current prices are employed in the second part (3.2.4-5). For the sake of clarity, taxes and income transfers are ignored, though they are included in the full model. Only 2 sectors are included - the transport sector and all other sectors (conventional production). There is no division into activities, factors, institutions, needs and commodities as in the social accounting framework.

**3.2.2 Conventional production - fixed prices<sup>2</sup>.**

First, factor income by place of production is determined by gross output (in figure 4 cell AE):

$$yaf = YAFQ \cdot xaf \dots\dots\dots(6)$$

Where:

*yaf*: GDP at factor cost by place of production, a

*YAFQ*: GDP at factor cost as share of (Q) gross output, at place of production

*xaf*: Gross output, by place of production

Gross output by place of production is transformed into disposable income at place of residence by subtracting commuting costs from income (from cell AE to BH):

$$ybf = \sum_a (1 - ETCABFQ) \cdot YABFQ \cdot yaf \dots\dots\dots(7)$$

Where:

*ybf*: Disposable income (income net of transport expenditure) by place of residence b

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<sup>2</sup>In this section, almost all variables are in fixed prices, indicated with an F or f in the variable name.

*YABFQ*: GDP at factor cost by place of residence as share of GDP at factor cost, by place of production

*ETCABFQ*: Demand for transport commodities (TC: commuting costs) as share of GDP at factor cost, by place of production and place of residence

The input to this step (*ETCABFQ*) comes from the transport model. In the following other elements of transport costs are obtained from the transport model.

Private consumption by place of residence is calculated as follows (from cell BH to BW):

$$cptbf = CPBFQ \cdot ytbf \dots\dots\dots(8)$$

Where:

*cptbf*: Private consumption, cp, by place of residence b

*CPBFQ*: Private consumption as a share of disposable income by place of residence

Private consumption by place of demand is calculated (from cell BW to DV):

$$cpdf = \sum_b (1 - ETSBDFQ) \cdot CPTBDFQ \cdot cptbf \dots\dots\dots(9)$$

Where:

*cpdf*: private consumption by place of demand d

*CPTBDFQ*: Private consumption by place of demand as a share of private consumption, by place of residence

*ETSBDFQ*: Demand for transport commodities (TS: costs of shopping trips) as share of private consumption, by place of residence and place of demand

Intermediate consumption is determined by gross output (from cell AE to DV):

$$xrdf = (1 - YAFQ) \cdot xaf \dots\dots\dots(10)$$

Where:

*xrdf*: Intermediate consumption by place of demand

Total local demand is given by (cell DV):

$$edf = xrdf + cpdf + codf + idf \dots\dots\dots(11)$$

Where:

*edf*: Total local demand by place of demand

*codf*: public consumption by place of demand

*idf*: investment by place of demand

*codf* and *idf* are, in this simple version of the model given exogenously, whilst they are modelled in the full version.

Local demand which is supplied domestically is determined by subtracting foreign imports (cell DV):

$$elodf = edf - mudf \dots\dots\dots(12)$$

Where:

*elodf*: domestically supplied local demand by place of demand

*mudf*: foreign imports by place of demand

Domestic production is determined by a trade model (from cell DV to AV):

$$xloaf = \sum_d (1 - ETTLOADFQ) \cdot ELOADFQ \cdot elodf \dots\dots\dots(13)$$

Where:

*xloaf*: gross output for domestic demand by place of production a

*ELOADFQ*: Gross output for domestic demand by place of production as share of gross output for domestic demand, by place of demand

*ETTLOADFQ*: Demand for transport commodities (TTLO: cost of trade trips for the interregional and intraregional market) as share of domestic (intra- and inter- regional trade) trade, by place of production and place of demand

Foreign export is determined by subtracting transport costs (cell AV):

$$euaf = \sum_w (1 - ETTUAWFQ) \cdot eutawf \dots\dots\dots(14)$$

Where:

*euaf*: foreign exports by place of production

*ETTUAWFQ*: Demand for transport commodities (TTU: cost of trade trips abroad) as share of foreign exports by country group and by place of production

*eutawf*: foreign exports by country group and by place of production

By adding foreign exports, local production can be calculated (from cell AV to AE):

$$xaf = xloaf + euaf \dots\dots\dots(15)$$

### 3.2.3 Production in the transport sector – fixed prices

As can be seen from this brief model description, transport costs enter into the model in different ways. First, for households, transport costs appear in relation to commuting as a deduction from household income and purchases of goods include transport costs involved with transporting the goods to place of residence. Second, for firms, wage costs are gross and include payment of commuting costs. It is assumed that the seller pays transport costs (fob). The firms' revenues on sale of commodities therefore exclude transport costs.

The approach used here is the inverse *iceberg concept* (Samuelson 1954) implying the inverse of the idea that a part of the commodities disappear on the way to the market. The cost approach used here corresponds to an increase in the price of the product under transport to the market.

Demand for transport can be determined by adding up (relating interaction cells to cell AV):

$$\begin{aligned}
 etdf &= \sum_d ETTLOADFQ \cdot ELOADFQ \cdot elodf \\
 &+ \sum_b ETSBDFQ \cdot CPTBDFQ \cdot cptbf \quad \dots\dots\dots(16) \\
 &+ \sum_a ETCABFQ \cdot YABFQ \cdot yaf
 \end{aligned}$$


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Assuming that transport is an immobile<sup>3</sup> commodity, gross output in transport sector is by definition equal to gross output in transport sector:

$$xtaf = etdf$$

**3.2.4 Conventional production - current prices<sup>4</sup>.**

Economic activities in current prices are modelled using a mark-up principle. Gross output in current prices is determined as follows (in figure 5 cell AE) :

$$xa = px \cdot xraf + pya \cdot yaf \quad \dots\dots\dots(17)$$

Where:

- xa*: gross output by place of production a
- px*: output price index
- pya*: GDP at factor prices at place of production

Implicitly an output price index can now be determined (cell AE):

$$px = \frac{xa}{xaf} \quad \dots\dots\dots(18)$$

In a similar way, output prices for transport sector (*pxt*) can be determined.

GDP at factor prices by place of production is transformed into disposable income at place of residence by subtracting commuting costs from income (from cell BH to AE):

$$ytb = \sum_a (pya - pxt \cdot ETCABFQ) \cdot YABFQ \cdot yaf \quad \dots\dots\dots(19)$$

Where:

- ytb*: Disposable income (income net of transport expenditure) by place of residence b
- production
- pxt*: output price index for transport sector

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<sup>3</sup>More realistically, transport activities are mobile, allowing for trade with transport services between regions. In order to simplify, this simple model the transport sector is assumed to be non-mobile. In the extended model, described later, transport activities can be assumed to be both mobile and non-mobile.

<sup>4</sup>In this section most variables are in current prices. For current price variables the F or f –postfixes are excluded.

*ETCABFQ*: Demand for transport commodities (TC: commuting costs) as share of GDP at factor cost, by place of production and place of residence

Output prices for conventional production together with output prices for transport sector (*p<sub>xt</sub>*) determine the export prices by country group (from cell AE to AV):

$$eutaw = \sum_w (px - pxt \cdot ETTUAWFQ) \cdot eutawf \dots\dots\dots(20)$$

Where:

*eutaw*: foreign exports by place of production in current prices

Implicitly, a price index for foreign exports by country group can now be determined (cell AV):

$$peutaw = \frac{eutaw}{eutawf} \dots\dots\dots(21)$$

Where:

*peutaw*: price index for foreign exports by country group.

The foreign export price index determines the real foreign export (cell AV):

$$eutawf = f(peuawt, peew, fEew) \dots\dots\dots(22)$$

Where:

*peew*: price index for production abroad by country group w

*fEew*: proxy for export demand by country group

Inter- and intraregional trade (domestic demand) can be calculated (cell AV):

$$xloa = xa - euta \dots\dots\dots(23)$$

Inter- and intraregional trade, including transport cost, in current prices, can be calculated (from cell AV to DV):

$$\begin{aligned} eload &= eload + ettload \\ &= (px + pxt \cdot ETTLOADFQ) \cdot ELOADFQ \cdot xloaf \dots\dots\dots(24) \end{aligned}$$

Implicit price indices for inter- and intraregional trade (*peload*) and domestic supply (*pelod*) can be determined (cell DV):

$$peload = \frac{eload}{eloadf} \dots\dots\dots(25)$$

$$pelod = \frac{elod}{elodf} = \frac{\sum_a eload}{\sum_a eloadf}$$

Foreign imports in current prices can be determined (cell DV):

$$mud = pmu \cdot mudf \dots\dots\dots(26)$$

Local demand in current prices and a price index for local demand can now be determined (cell DV):

$$ed = elod + mud \dots\dots\dots(27)$$

$$ped = \frac{ed}{edf}$$

Where:

*ed*: local demand by place of demand d

*mud*: import from abroad

The foreign import (*mudf*) can be determined by the following function (cell DV):

$$mudf = f(edf, pelod, pmu) \dots\dots\dots(28)$$

After deducting foreign import from local demand, domestic production for local market can be distributed among exporting region according relative prices. Using a Cobb-Douglas formulation the import shares are determined in the following way (cell DV):

$$ELOADFQ = \frac{\frac{eloadq}{peload / pelodv}}{\sum_a \frac{eloadq}{peload / pelodv}} \dots\dots\dots(29)$$

Local demand in current prices by type can now be determined (from DV to DW):

$$xr = ped \cdot xrf$$

$$cpd = ped \cdot cpdf \dots\dots\dots(30)$$

$$cod = ped \cdot cof$$

$$id = ped \cdot idf$$

Shopping flows in current prices (between place of demand and place of residence) and an implicit price index for these flows can be determined (from cell DW to BW):

$$cptbd = (ped + petd \cdot ETSBDFQ) \cdot CPTBDFQ \cdot cpdf \dots\dots\dots(31)$$

$$pcptbd = \frac{cptbd}{cptbdf}$$

Private consumption by place of residence in current prices and an implicit prices index for this variable can be calculated (cell BW):

$$cptb = \sum_d cptbd \dots\dots\dots(32)$$

$$pcptb = \frac{cptb}{cptbf} = \frac{\sum_d cptbd}{\sum_d cptbdf}$$

Where:

*CPTBDFQ*: Private consumption by place of residence as a share of private consumption, by place of demand

Private consumption demand by place of residence can be distributed among shopping regions (place of demand) according relative prices. Using a Cobb-Douglas formulation the shopping shares are determined in the following way:

$$PCPTBDFQ = \frac{\frac{cptbdq}{pcptbd / pcptb}}{\sum_d \frac{cptbdq}{pcptbd / pcptb}} \dots\dots\dots(33)$$

**3.2.5 Production in the transport sector – current prices**

In calculation of production in current prices as shown in section 2.3.4 purchase of transport commodities in current prices enters. Calculation of purchase of transport commodities in current prices is made by multiplying purchase of transport commodity in fixed prices (for example in equation (19) *ETCABFQ*) by a price index for transport commodities (*pxt*). The price index is calculated implicitly:

**3.2.6 The full model**

In the full model a more detailed treatment is to be found. In relation to analysis of transport, a number of significant elements can be identified.

First, the full model distinguishes between mobile and immobile commodities. Mobile commodities are transportable commodities whilst for immobile commodities place of demand is by definition the same as place of production, including various forms of private and public service, for example hairdressing and hospitals. For immobile commodities the relation between demand and supply of

commodities direct as there is no interregional trade and therefore there are no transport costs. In the case of hairdressing the problem of transport costs is related to shopping trips.

Second, different price concepts are used. Commercial margins and net commodity taxes enter into the full model and in relation to the transport commodity this means that the price depends on the size of net commodity taxes (for example fuel taxation and subsidies for fixed links). Commercial margins depend on the concrete situation, for example in the case of Øresund whether or not economic rents are extracted in the form of monopoly profit.

Third, in the full model the transport sector is subdivided into different transport subsectors. In the case of the fixed Øresund link a bridge and a ferry subsector are relevant. Each has different productivity and employment levels.

For a general treatment of data construction and modelling in the full model see (Madsen & Jensen-Butler 1998b)

#### **4. Modelling effects of infrastructure investments**

In this paper a new approach to classification and modelling of the effects of changes in the transport sector is modelled. The approach is derived from use of the interregional general equilibrium model as described in section 2.

##### **4.1 Introduction**

Jensen-Butler & Madsen (1999) identify three different elements in modelling the medium-term regional economic effects of transport infrastructure investment:

1. The effects of changes in transport technology
2. The effects arising from changes in transport flows in different transport corridors.
3. The effects arising from changes in levels of regional competitiveness

Changes in transport technology include, for example, a transition from ferry links to a fixed link. This type of change has direct consequences for these transport activities and indirect consequences for the broader regional economy. Changes in transport flows generate changes in the economy through other transport sub-sectors (competing ferry routes, for example) and in other direct transport-related sectors (hotels and restaurants, for example) as route-choice changes. Changes in regional competitiveness for the region's sectors in general as a consequence of changes in the transport sector have both a direct effect on production and indirect effects on the regional economy.

In a general equilibrium approach as described above the analysis is somewhat different.

##### **4.2 Decomposition of effects of the fixed Øresund link in an interregional general equilibrium modelling framework**

The three sets of effects referred to above can be reformulated in a general equilibrium framework as follows, in the context of an ex post analysis. In relation to the ex post analysis described in equation (5) the effect of the fixed Øresund link is a reduction in transport costs. This means that the decomposition equation can be reformulated as follows:



$$\begin{aligned}\Delta T_{ij}^{pmr,\emptyset F} &= (M(E_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1})) \\ &= (M(TC_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M(TC_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}))\dots\dots(34)\end{aligned}$$

The calculation of this element of the decomposition can be divided into three different elements. In each of the three elements a constraint has been placed on the model:

$$\begin{aligned}\Delta T_{ij}^{pmr,\emptyset F} &= (M_3(E_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M_3(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1})) \\ &= (M_3(C_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M_2(C_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1})) \\ &+ (M_2(C_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M_1(C_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1})) \\ &+ (M_1(C_{TR}^{\emptyset F,t_1}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}) - M_3(C_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_1}, E_{ECON}^{t_1}))\dots\dots\dots(35) \\ &= \text{consequences of change in regional competitiveness} \\ &+ \text{consequences of change in transport activities} \\ &+ \text{consequences of changes in transport technology}\end{aligned}$$

In the model  $M_1$  it is assumed that changes in transport costs do not affect choice of mode or route in the transport model and the price circuit in LINE. The only change which occurs is that bridge production replaces ferry production which affects employment and income in the transport sector and in turn affects the regional economy. This corresponds to the effects of changes in transport technology referred to in section 4.1.

In the model  $M_2$  the transport model creates changes in traffic flows, whilst changes in transport costs still do not affect the regional economic model directly. Changes in traffic flows by mode and route generate changes in the output of the transport sector and, as a consequence, the output of sectors which supply the transport sector with intermediate commodities. This corresponds to both the first and second set of effects referred to in section 4.1. The marginal effect of the second set can easily be calculated by subtraction.

Finally, in the model  $M_3$  changes in transport costs also affect regional competitiveness through direct impacts in the pricing mechanism of the effects of changed transport costs. This corresponds to the sum of all three effects described in section 4.1. Again, the marginal effect of changed competitiveness alone can easily be calculated.

## 5. Border barrier effects

A problem which is often compounded with the evaluation of the effects of major transport infrastructure investments is that of separating out the economic effects from the pure effects from the infrastructure change. In the case of the Channel Tunnel the problem was to separate the effect of the internal market from that of the transport system improvement. In the case of the Øresund link the corresponding issue is the question of border barriers, especially in the light of Sweden's recent membership of the EU. In technical terms, this involves the third element in the decomposition (see equation (5)). On this basis it is possible to undertake a decomposition involving effects arising from reduction in border barriers and effects of other exogenous changes in the economy:

$$\begin{aligned}
 \Delta T_{ij}^{pmr,ECON} &= (M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_1}, E_{ECON,OTHER}^{t_1}) \\
 &\quad - M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_0}, E_{ECON,OTHER}^{t_0})) \\
 &= (M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_1}, E_{ECON,OTHER}^{t_1}) \\
 &\quad - M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_0}, E_{ECON,OTHER}^{t_0})) \\
 &\quad + (M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_0}, E_{ECON,OTHER}^{t_1}) \\
 &\quad - M(E_{TR}^{\emptyset F,t_0}, E_{TR}^{OI,t_0}, E_{ECON,BORDER}^{t_0}, E_{ECON,OTHER}^{t_0})) \dots \dots \dots (36)
 \end{aligned}$$

Border barriers enter directly into the regional economic model in the equation for interaction. In the case of interregional trade (equation (13)) market share (ELOADFQ) is a function of transport costs and border barriers.

## 6. Conclusions

The paper examines from a methodological and theoretical point of view the consequences for traffic flows and for regional economies of a major transport infrastructure investment, here the fixed link across the Øresund between Denmark and Sweden.

The focus of the paper is ex post evaluation of major traffic infrastructure investments, in contrast to ex ante analyses which dominate the literature. Ex post analysis starts with observed changes in traffic flows and in regional economic variables. The point of departure in ex post evaluation is the observed changes and the methodological problem is to decompose these changes into components which permit identification of the relative contributions of different factors: the effect of the fixed link, the effect of other transport infrastructure investments and changes in regional economic activity, including changes in interregional interaction. It is argued that only an integrated transport and regional economic model can perform this type of analysis. In order to illustrate how the contribution of effects of changes in regional economies is evaluated an interregional general equilibrium model is presented.

The sub-component which deals with the effect of the fixed link is further subdivided into components reflecting changes in transport technology, changes in transport patterns and changes in relative regional competitiveness arising from improved accessibility. The decomposition method in this case is a stepwise process where model components are made endogenous.

The sub-component dealing with the effect of the regional economic consequences is subdivided into changes due to reductions in border barriers and changes due to general economic development and the method proposed is again a successive stepwise process making components endogenous.

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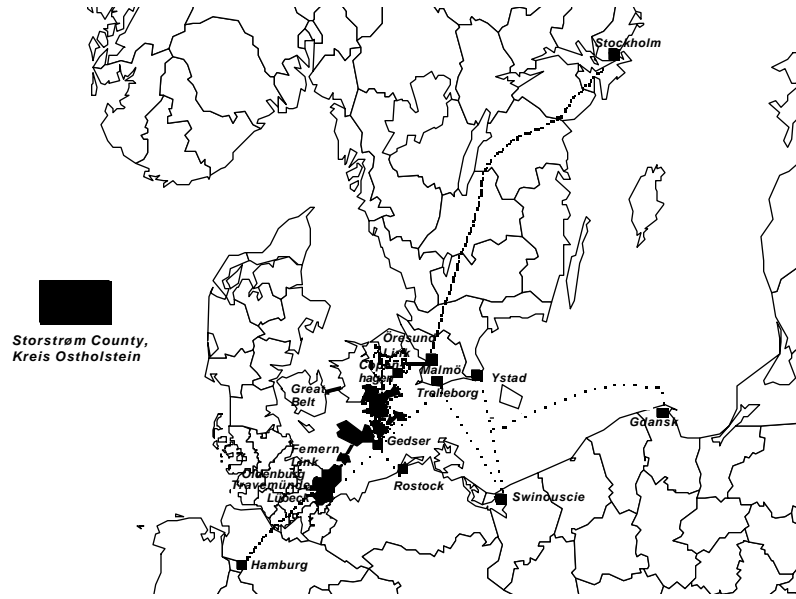
**Table 1: Characteristics of the three fixed links**

	Travel times <sup>1</sup> car and lorry		Lenght km	Ticket price	Opening date
	Before	After			
Great Belt	75	17	18	as today <sup>2</sup>	1997
Øresund	75	20	22	as Helsingør/ Helsingborg ferry	2000
Femern	90	20	22	as today <sup>2</sup>	?

1 Including terminal time and assuming bridge/tunnel for cars and trains.

2 Driving costs whilst using the link not included.

Figure 1



**Figure 2: An ideal model:  
An integrated model for transport and regional economic change**

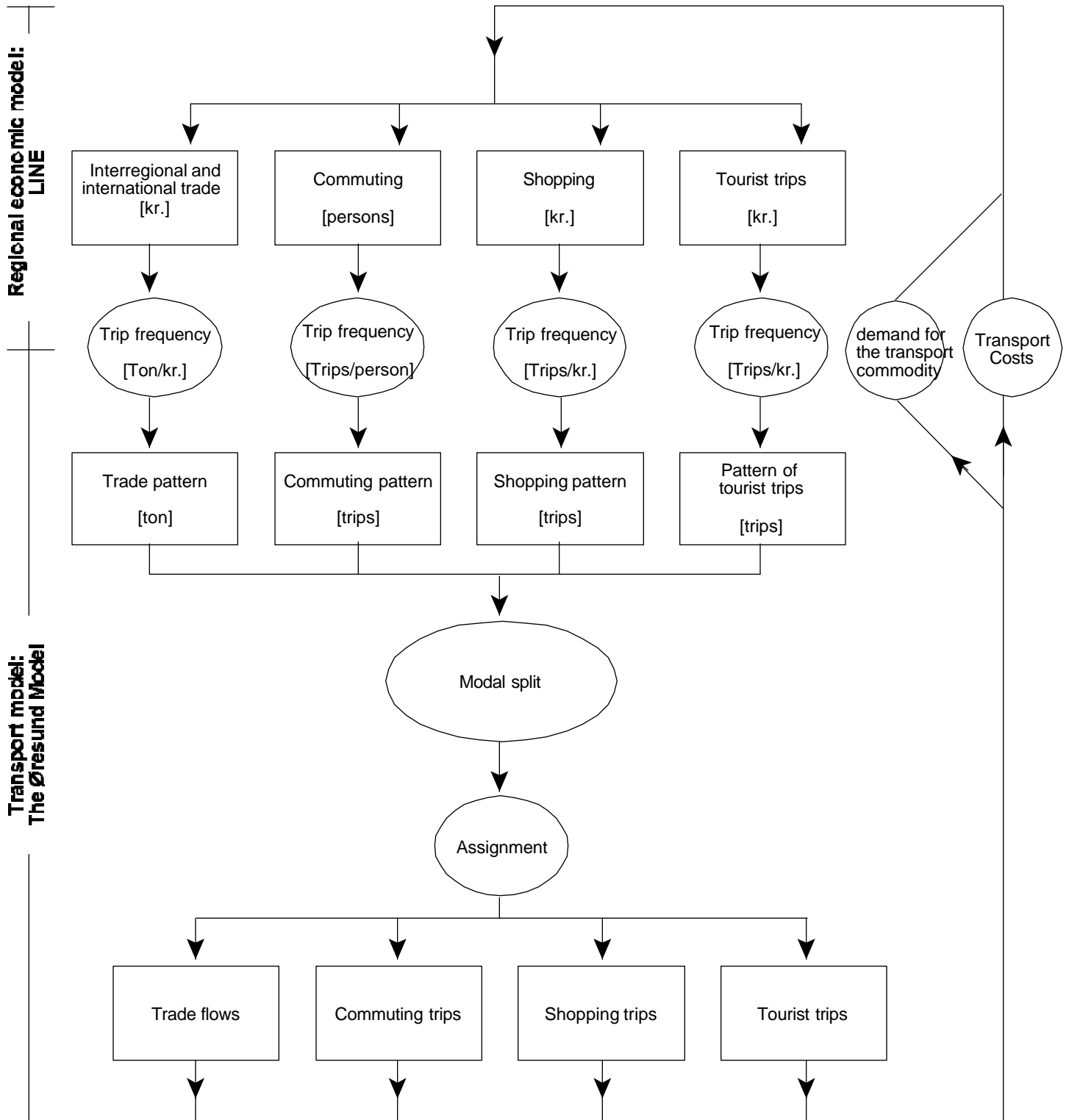




Figure 3 LINE – the Real Circuit

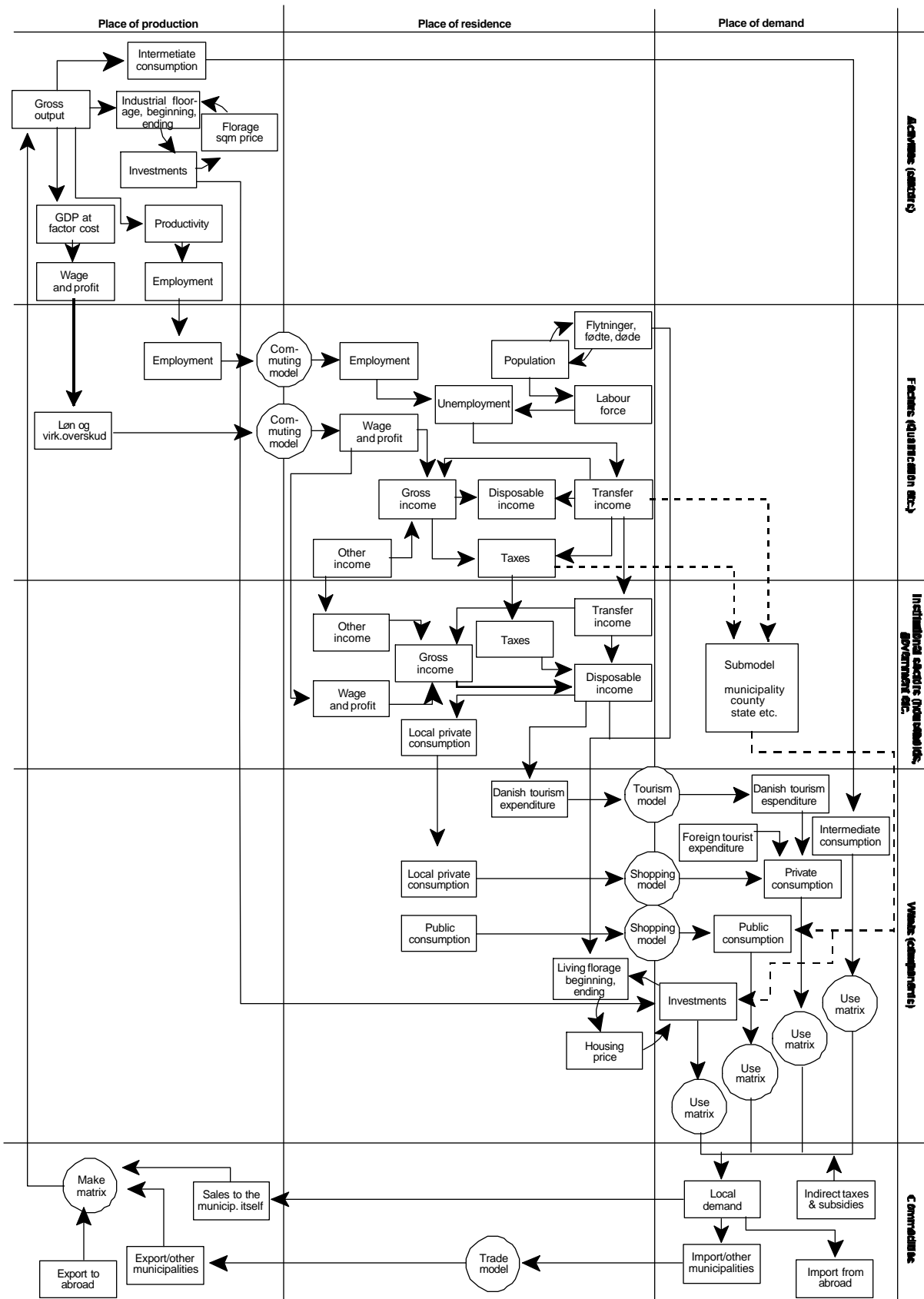


Figure 4 Simplified version of LINE. The real circuit

	Place of production	Place of residence	Place of demand
Activities (Sectors)	Gross Output GDP at factor prices (AE)		
Factors of Production (education, gender, age)	Wages and profits Employment (AG)	Wages and profits Employment Unemployment Taxes and transfers Disposable income (BG)	
Institutions (households, firms, public sector)		Wages and profits Taxes and transfers Disposable income (BH)	
Demand components		Local private consumption Residential consumption Tourist expenditure Public consumption Investments (BW)	Intermediate consumption Local private consumption Tourist expenditure Public consumption Investments (DW)
Commodities	Local production Exports to other municipalities Exports abroad (AV)		Local demand Imports from other municipalities Imports from abroad (DV)

————— Constant prices

- - - - - Current prices

Figure 5 Simplified version of LINE. The price circuit

	Place of production	Place of residence	Place of demand
Activities (Sectors)	Gross Output GDP at factor prices (AE)		
Factors of production (education, gender, age)	Wages and profits Employment (AG)	Wages and profits Employment Unemployment Taxes and transfers Disposable income (BG)	
Institutions (households, firms, public sector)		Wages and profits Taxes and transfers Disposable income (BH)	
Demand (components)		Local private consumption Residential consumption Public consumption Tourist expenditure (BW)	Intermediate consumption Local private consumption Public consumption Investments (DW)
Commodities	Local production Exports to other municipalities Exports abroad (AV)		Local demand Imports from other municipalities Imports from abroad (DV)

- Basic prices (exclusive transport costs)
- - - - - Market prices
- Basic prices (inclusive transport costs)

